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The Corps of Engineers. U.S. Fish and Wildlife Service and the Environmental Protection Agency are charged the responsibility to jointly manage the nation's wetlands in accordance with the Clean Water Act and the Rivers and Harbors Act. The Corps' role is enforcement of regulations concerning dredging and filling of specific types and areas of wetlands that fall within jurisdictional boundaries.

Current research is being conducted to enhance the field scientist's ability to manage these ecosystems using digital aerial photography, image processing and photo interpretation logic. This paper presents techniques used to scan (digitize), archive and use digital aerial photography for environmental resource management using a photogrammetrically accurate, CCD-based scanner. Spectral characteristics of the imagery and useful image processing routines to enhance the resulting raster file(s) for interpretation will be discussed.

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Using digital scanned aerial photography for wetlands delineation

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ABSTRACT

The Corps of Engineers, U.S. Fish and Wildlife Service and the Environmental Protection Agency are charged with the responsibility to jointly manage the nation's wetlands in accordance with the Clean Water Act and the Rivers and Harbors Act. The Corps' role is enforcement of regulations concerning dredging and filling of specific types and areas of wetlands that fall within jurisdictional boundaries.

Current research is being conducted to enhance the field scientist's ability to manage these ecosystems using digital aerial photography, image processing and photo interpretation logic. This paper presents techniques used to scan (digitize), archive and use digital aerial photography for environmental resource management using a photogrammetrically accurate, CCD-based scanner. Spectral characteristics of the imagery and useful image processing routines to enhance the resulting raster file(s) for interpretation will be discussed.

2. ENVIRONMENTAL MONITORING

Recently, there has been a move in this country to recognize the vital functional value of wetlands. These ecosystems are found in two regimes, tidal and nontidal, and provide a host of natural benefits including waterfowl breeding, flood control, pollution abatement, water quality enhancement, and shoreline stabilization. The Corps of Engineers is experimenting with the use of digital aerial photography as a source of information to manage and protect these resources for the future. Currently, within the Corps of Engineers, a prototype system exists which exploits high-resolution, digital aerial imagery. The Environmental Monitoring System (EMS) uses digital photography to evaluate public lands under the jurisdictional control of the Corps.

The EMS fuses personal computer image processing, a geo-based information system, mensuration tools and report generation techniques to provide an effective solution for field scientists charged with managing large tracts of land. The EMS is capable of assisting field scientists derive solutions to mitigation problems and investigate violations of construction permit regulations. The main source of data input that makes this possible is the digital aerial photograph.

3. DIGITAL IMAGE REQUIREMENTS

As technology makes available faster and higher density storage mediums, high-resolution, digitized photography becomes more and more practical as an exploitable data resource. Various scan densities and resultant file sizes for digitized 9.5-inch by 9.5-inch photographs (film positives) are illustrated in Table 1 and Formula 1. These figures are based on scans performed using the Engineer Topographic Laboratories Image Digitizing System (IDS). Applications ranging from digital photogrammetry to image processing and analysis will require the use of various digital image data sets. Traditional aerial frame photography offers a useful high-resolution source of imagery for scanning. This photography is available in black and white, color and color-infrared. In addition, this imagery (9-inch by 9-inch) can be obtained as prints and film transparencies.

Advantages of aerial photography as applied to resource management are its availability in varied resolutions and the abundance of archived photographic records. These represent a vast data base which can be used in site

mitigation, change detection and multi-temporal analysis. For some areas of the continental United States, aerial photography dating from the 1920s and 1930s can be obtained. The ever-increasing responsibility of state and federal regulatory agencies to enforce laws governing the use of public lands will be enhanced by using this kind of data.

Table 1. **Data Resolutions and Comparative File Sizes**

Scanner Resolutions (microns)	File size (megabytes)
7.5	1023
15.0	254
30.0	64
60.0	16

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Data Values from the IDS

where: For a 240mm X 240mm photograph

@7.5μ pixel resolution
Linear Array = 2048
One Swath =

$$2048 \times \frac{240}{.0075} = 65.5mb$$

Number of Swaths Covered (limited by scanner) = 16

$$16 \times 65.5mb = 1.023gb$$

Formula 1.

4. SOURCE PHOTOGRAPHY

For earth resource imaging, where subtle differences occur in features, the use of black and white photography has been almost totally replaced by color systems. The human eye can distinguish up to 200 different shades of gray, but can detect some 7.5 million colors.[1] High-resolution, color-infrared photography has been proven the most useful source of data for the delineation of wetland habitats, both tidal and nontidal. The soil and vegetation moisture characteristics of wetlands represents strong and unique spectral signatures in the infrared, typically 700 to 1100 nanometers.[2] Emulsion sensitivities from color and color-infrared films (Aerochrome 2448 and Aerochrome IR 2443) are represented in Table 2. These were determined by using the film emulsion sensitivity curves generated by Eastman Kodak (1982).[3]

Table 2. **Emulsion Sensativities of Films**

Emulsion	Color†	Color IR††
Yellow (*blue)	400 - 530 nm*	400 - 610 nm
Magenta (*green)	430 - 600 nm*	400 - 680 nm
Cyan (*red)	450 - 700 nm*	400 - 925 nm

† Lower limit is set by haze filter, Wratten HP-3.
† † Lower limit is set by the Wratten #12 filter.

Some representative spectral curves for wetlands soil and vegetation are given in Figure 1. These measurements were collected with a hand-held Daedalus (Spectrafax) spectroradiometer with a bandpass of 400 to 2400 nm and a 15-degree field of view.

5. IMAGE DIGITIZING SYSTEM (IDS)

In order to preserve the color integrity and quality of detail in imagery, scanning must be performed precisely and interactively. The development of linear, time integrated charge-coupled devices (CCD) has made precision scanning a reality. The Image Digitizing System (IDS) at the Engineer Topographic Laboratories is a prototype of such a system. The IDS consists of a scanner (digitizer) and a host computer workstation (Figure 2). The scanner module is a high-precision flatbed photo stage with X and Y servos which position photographic transparencies ranging in size up to 10" X 10" (260mm X 260mm). The photo stage provides a positioning and measuring accuracy of 2-micron mean square error for the entire 10" X 10". A fan-cooled lamphouse with a Tungsten-Halogen lamp provides a stable source of illumination which is coupled to a condensor lens via a fiber optic bundle. The lamphouse contains a revolving set of filter wheels (red, green, blue and clear) providing the means to generate full color (24-bit) images from color film (Figure 3).

An image is collected via a corrected multi-element fixed optical system onto a linear (2048 element) CCD camera. The CCD camera board can be rotated +/- 10 degrees (from nominal) by a servomechanism. This allows 'off-axis' scans to be performed, correcting for loading errors (placement of film) for precise scanning at a precise orientation relative to the actual film photoaxis coordinate system (Figure 4). The digitized image from the CCD camera is routed to the host workstation by a special normalization/interface located in the scanner module. This provides for real-time camera normalization to compensate for all fixed illumination and CCD response non-uniformities, in addition to providing for pixel aggregation capabilities. Pixel aggregation allows for lower resolution data to be collected by the system without the inherent resolution losses in detail and other problems associated with movable optics.

6. SCANNING METHODOLOGY

Scanning aerial photography for environmental resource mangement presents several interesting problems. In the case of wetland habitat delineation, resolutions must be selected to enhance the textural qualities of surface vegetation as well as preserve the color spectral signatures detected with color infrared films. It is important to note that delineation does not necessarily mean identification. There is no substitute for ground truth verification of species indicators. Large monotypic stands of vegetation, i.e. Maple (Acer), Willow (Salix) and Buttonbush (Cephalanthus) should be indentifiable on high-resolution, large-scale photography, but in the event small scale imagery is used, wetland and upland boundaries may be all that is distinguishable. Plant types can be inferred using photo-interpretation logic guidelines developed by R.E. Frost (in the late 1940s and early 1950s) at Purdue University. Deductive and inductive reasoning applied to the careful examination of landforms, drainage, vegetation textures, cultural features, erosion and deposition provide clues to help identify features.[4]

To enhance the ability to interpret scanned imagery, control over scan resolution, integration time and post-scan processing is important for preservation of detail. For color and color IR photography, color balancing is essential to maintain the appearance of the resultant digital image. Going from an analog to a digital image can alter colors and misrepresent subtle tones that indicate environmental conditions, e.g., shades of red in infrared false-color photos indicate different vegetation types and levels of vegetation health, maturity or seasonal condition.

6.1 RESOLUTION.

Determining the optimal resolution to scan is controlled by three factors: 1) Maintaining the detail of features to

evaluate and interpret, 2) The capability of the scanning device, and 3) Host disk space for storage and random access memory. As illustrated in Table 1, file sizes vary greatly with change in resolution. A higher scanning resolution (30 or 60 microns) may be adequate for broad coastal areas; however, small bottomland hardwood communities may require a smaller (7.5 to 15 micron) resolution. The IDS scanner at the Engineer Topographic Laboratories is capable of scanning from fine resolutions of 7.5 microns to coarse resolutions of 120 microns. Images at resolutions from as fine as 7.5 microns for making precise measurements of film features, along with aggregated resolutions of 15 and 30 microns for photogrammetric-quality images can be achieved in as little as 10 minutes. More coarse resolutions of 60 and 120 microns for overview images of entire films can be achieved in as little as 4 minutes. Overview images can be utilized for selecting photogrammetric tie points and control points and for specifying regions of interest for scan control purposes. Illustrated in Table 3 are examples of identifiable features for four scan resolutions over the same geographic area. The ecology of the area is a coastal estuary near Ocean City, Maryland. Suspected violations of the Clean Water Act are being evaluated by examining back water draining and filling of wetlands for marina construction.

Table 3. **Features and Resolutions**

Scanned Aerochrome 2443 Color IR Film Positive:
Spectral Emulsion Sensitivity - Yellow 400-610nm,
Magenta 400-680nm, Cyan 400-925nm
Peak λ - Y = 550, M = 650, C = 750

Resolution	**Features**	**File Size (mb)†**
7.5 microns	Drainage canals, textures and colors of vegetation species. Excavation equipment, fill and spoils piles.	21,676,032 bytes
15 microns	" "	5,948,416 bytes
30 microns	Some vegetation color and texture. Detail becoming pixellated and blocky.	1,770,496 bytes
120 microns	Upland/wetland boundaries. Little detail showing fill operation.	197,632 bytes

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† 20mm by 20mm patch

6.2 COLOR BALANCING

Comparison of Table 2 and Figure 1 reveals that wetland habitats imaged by color IR photography are indicated most strongly in the cyan emulsion. For reversal films like Aerochrome IR 2443, density of the dye formed during processing is inversely related to the Reflectance Emulsion Factor (REF). REF values indicate the relative effect of light from the sample on the film emulsion layer. Although these values do not take into consideration the relation between exposure and dye layer densities, these general relations are seen.

For example, shaded soil and shaded vegetation, which have low REF values, appear dark in either color or color IR film. Sunlit, bright surfaces with high REF values would appear bright. The image color of a surface depends on the emulsion layer(s) affected and the density of the dye layer formed on the film. For green vegetation, which appears red on color IR film, the REF values are low in the yellow and magenta emulsions and high in the cyan emulsion. The cyan layer modulates the infrared in color IR photographs. While healthy vegetation will appear as various shades of red, vegetation may also appear as shades of blue, gray or green. Inundated vegetation and vegetation under environmental stress or seasonal senescence will have a low spectral signature in the infrared.

Interpretation of these areas can be affected by soil moisture content, plant spacing, turbidity and shadows.

When scanning color IR photography, preservation of colors can be accomplished (to a degree) by color balancing. This involves calibrating the scanner and adjusting the integration times for each color filter used in the scanning process. Integration time can be thought of as analogous to exposure time in film development. CCD calibration is performed by scanning calibration targets in the scanner with each filter wheel and obtaining pixel intensity values or histograms. These determine how much exposure the array will give each red, green and blue filter.

Since we are color calibrating using black and white patches, histograms (intensity levels) are used to adjust the relative integration time for each color. This is accomplished by finding the most prominent color in an image and determining its integration time for a histogram with no saturation. This is done by performing a coarse overview scan to obtain the histogram data sets for each red, green and blue scan. Photographs with a high level of red may require a lower integration time for that color, conversely a higher integration time may be required for colors that do not represent much information in an image, i.e., the green component of a color IR photo. Integration values are a function of time and are adjusted according to pixel intensity. Heavy emulsions may also govern integration time. Figure 5 represents the histograms of two different scans, one calibrated for color and the other scanned without color balancing. The gray scale values are plotted on the X axis against the intensity levels found on the Y axis.

7. IMAGE PROCESSING/ENHANCEMENT

Digital aerial photography offers a new opportunity to apply traditional remote sensing and image processing classifiers, filters and statistical algorithms. Since the digital files represent the spectral information contained within the source emulsions, operations utilized for satellite multispectral and hyperspectral digital imagery can be applied both in practice and in theory. Advantages of high-resolution, color infrared aerial photography are both its spectral and spatial information. Photos that are rectified and co-registered to the nearest pixel can be processed by algorithms such as Kauth-Thomas Brightness-Greenness, Kinematsu Vegetation Index, Deering Transformed Vegetation Index, traditional normalized difference and simple band ratioing to produce special products images. Experiments at the Engineer Topographic Laboratories have produced limited success with supervised and unsupervised classification as applied to infrared aerial photography.

Geometric correction of digital aerial photographs has initiated a new field in digital photogrammetry. High resolution data sets can be rectified to produce digital stereo models that can be displayed on readily available stereo display monitors. Digital aerial photographs and space-borne digital imagery can be rectifid by using special transformations like the IHS (intensity, hue and saturation) transform.

For the delineation of natural resources like wetlands, spatial filtering operations are very useful. Convolution filters such as high and low pass matrices are easily applied to digital photos to perform edge enhancements or supress certain features. For coastal areas, high pass filter matrices have been useful to enhance the subtle textures associated with submerged and emergent aquatic vegetation, and to assist in delineating boundaries between wetland and upland.

8. CONCLUSION

This report has introduced some concepts surrounding the use of high resolution digital aerial photography for natural resource management. From recent innovations in scanning and photo-optical technologies has arrived a means to digitally extract information contained in film-based mediums. Aerial photographs present a wealth of information in an archived form that is readily available as a data resource for many scientific and engineering applications.

The Corps of Engineers is investigating digitized aerial photography as a tool to help regulate and enforce environmental laws. Although the use of aerial photography may be initially perceived as a step backward, it has opened a new dimension in image media made possible by the advent of scanning. There are a multitude of issues

that still need to be understood about image scanning, in particular, the gains and losses of information when chemical emulsions are converted into electronic numbers. There is also a need to explore issues dealing with the preservation and enhancement of detail in digital photos.

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